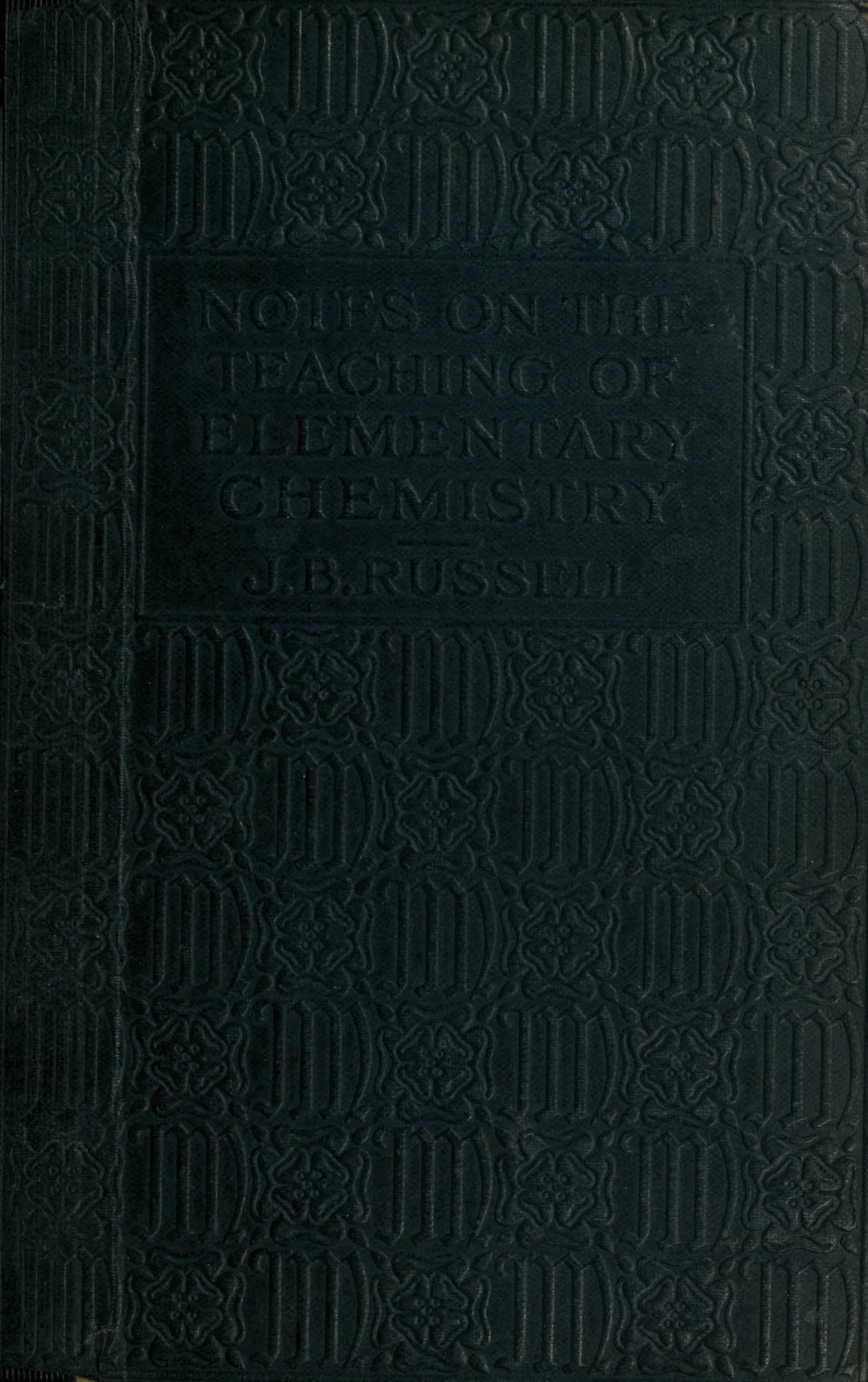

NOTES ON THE TEACHING OF ELEMENTARY CHEMISTRY

J. B. RUSSELL

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NOTES ON THE TEACHING OF ELEMENTARY CHEMISTRY

WITH A SEQUENCE OF EXPERIMENTS ON AIR AND COMBUSTION

TEACHER'S EDITION

BY J. B. RUSSELL, B.Sc. (Lond.)

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NOTES ON ELEMENTARY CHEMISTRY. VOL. I.

PART I.—PRELIMINARY EXPERIMENTS. } *In preparation.*
PART II.—AIR AND COMBUSTION. }

NOTES ON VOLUMETRIC ANALYSIS. By J. B. RUSSELL, B.SC. (LOND.), and A. H. BELL, B.SC. Revised and Enlarged Edition. Crown 8vo. 2s.

PREFACE

This book is intended primarily for the use of teachers of chemistry in day schools of all grades; but it is hoped that it will also prove useful in certain preparatory evening classes. The Introduction deals with some points of difficulty in the teaching of Elementary Chemistry; this is followed by a sequence of experiments to illustrate the method of teaching proposed.

The pupil's book, *Notes on Elementary Chemistry*, Vol. I., is published separately. It contains,—

Part I.—A Sequence of Preliminary Experiments.

Part II.—A Sequence of Experiments dealing with the Chemistry of Air, together with supplementary matter.

Part II. is incorporated in the present volume. In the preparation of this book an effort has been made to solve some of the difficulties which have for a long time been the subject of discussion by science teachers. A filing arrangement (as exemplified on p. viii) is used instead of ordinary binding. The teacher is thus enabled to distribute to his class the separate pages or sections *at a time when he thinks it expedient that his pupils should possess a printed record of experiments, discussions, or supplementary matter.* The difficulty that a text-book forestalls the practical work is thus overcome. When the pupil has written his own record (and not until then) he is allowed to file the section of the book which deals with the work done. Thus a permanent record is gradually put together, which will ultimately serve as a book of reference for the work of the whole course.

References to the sources of experiments are, where possible, given in the text, and attention is called to the Appendices.

I should like to express my indebtedness to Mr. F. W. Westaway for welcome advice and encouragement during the compilation of the book; and to Dr. Lowry and Mr. T. P. Nunn for help in correcting the proofs.

J. B. R.

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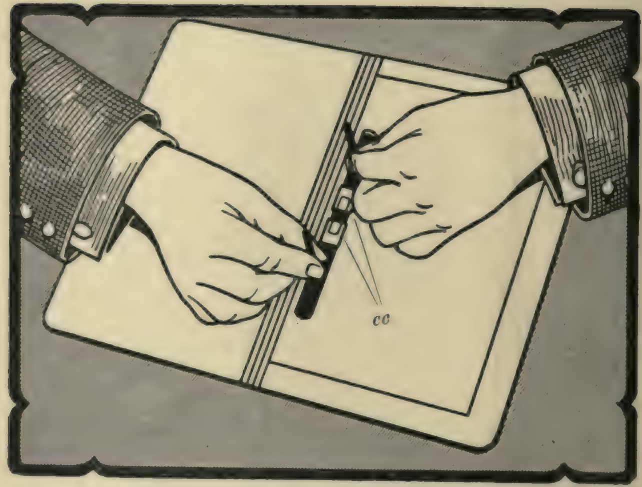
NOTES.—(1) This table of contents does not appear in the pupil's book, and the introduction and appendices are omitted.

(2) For convenience of publication the separate sections **A—T** are filed and issued in book form. It is recommended that at the first meeting of the class the sections should be removed from the files, one at a time, and collected in piles.

These sections should then remain in the custody of the science master until the time fixed for their distribution.



How to use the Files.

Unlock by pushing catches (*cc*) towards the centre of the steel strip. Grip the prongs at the base and bend them upright; then remove steel strip; thread papers to be filed over prongs and replace steel strip. Press down papers and bend down prongs. Lock by pushing the catches ½ in. over the prongs when bent down.

NOTES ON THE TEACHING OF ELEMENTARY CHEMISTRY

METHODS OF SCIENCE

"(1) *Observation* of facts—including under this head that *artificial observation* which is called *experiment.*

"(2) That process of tying up similar facts into bundles, ticketed and ready for use, which is called *Comparison* and *Classification,*—the results of the process, the ticketed bundles, being named *General propositions.*

"(3) *Deduction,* which takes us from the general proposition to facts again—teaches us, if I may so say, to anticipate from the ticket what is inside the bundle. And finally—

"(4) *Verification,* which is the process of ascertaining whether, in point of fact, our anticipation is a correct one.

"Such are the methods of all science whatsoever."

THOMAS HENRY HUXLEY.[1]

INTRODUCTION

§ 1

THE TEACHING OF ELEMENTARY CHEMISTRY

FOR many years individual work in a laboratory has been recognised as an essential part of any scheme of science instruction intended for secondary schools. This type of work is, however, a comparatively modern growth.

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[1] *Huxley's Essays,* "On the Educational Value of the Natural History Sciences."

In the old days (I write of the condition of affairs ten to fifteen years ago) the teaching of chemistry in secondary schools was in the majority of cases restricted to class work or to lectures illustrated by experiments. The pupil obtained little, if any, first-hand knowledge of instruments or of substances. His latent powers of observation were cultivated to a very limited extent, and he was rarely called upon to exercise any initiative. The course was systematic, and largely confined to the communication of facts.

In these early days laboratory practice was a luxury enjoyed only by the few; but in recent years there has been a swing of the pendulum, and "practical work" is now firmly established in the curriculum, sometimes to the exclusion of other and equally important matters. It is unfortunate that there appears to be a tendency among inexperienced teachers to conduct their work as if mere experiment and mere observation were the only necessary features of a course which has for its chief object the training of minds in scientific methods of thought. It is on this account, perhaps, that there are persons who are of opinion that individual practical work is of no more value than lecture table work; and one American writer has gone so far as to state that "chemistry has suffered from the irrepressible wave of laboratory madness which has swept over the whole educational world."

A course of experiments following one another in no rational order and with no definite aim may be truly regarded as "laboratory madness"; on the other hand, many teachers adopt the general principle that the teaching should proceed from observations made by the students themselves.

This position is, I think, unassailable provided that,—

(*a*) The experimental course is arranged in a logical sequence.

(*b*) Care is taken to amplify the work of the laboratory when this is necessary for purposes of continuity or completeness.

(*c*) The all-important duty of connecting together the facts of experiment by sufficient theory to form an intelligible story is not neglected.

In a word, there must be method in our "madness." We need perhaps to realise more fully that the educational value of an experiment reaches its maximum only when the student fully appreciates its purpose, suggests the means of carrying it out (as far as he may be able at the particular stage of his development), and performs the manipulative part of the work in his best style.

Again, the term "observation" implies more than an exercise of the senses. A time arrives when there should be an intelligent analysis of the "things seen" with due regard to the purpose in view.

The pupil's attitude of mind towards his work is of the utmost importance, and for this reason I believe the following are some of the points which need our attention:

(*a*) The adequate consideration of the purpose of an experiment.

(*b*) The cultivation of initiative—*e.g.* in devising apparatus.

(*c*) The careful interpretation of results.

(*d*) The comparison and correlation of the results of experiments in the same series.

(*e*) The collection and assimilation of the information thus obtained.

The following quotations from recent papers with regard to the objects to be aimed at in the teaching of science in day schools will no doubt be read with interest.

The head master of Bedales School, in his Presidential Address to the Froebel Society, 1905, dealt with some of the problems which are of fundamental importance in all educational work. After comparing the aims of the old educational methods with those of the new, he proceeded:

"If we try to encourage and utilise a boy's love of discovery by turning him loose, for instance, in a science laboratory, it is probable that the results, however surprising, will be more costly than valuable. The true initiative that we want to foster is not a butterfly flitting from whim to whim, but the pursuit, to its accomplishment, of a clearly designed purpose.

We are first to help him to single out a purpose that is in some degree possible of attainment; then to help him clearly to realise the means of attaining it; and lastly, to see that the pursuit is not abandoned before some sort of attainment is reached. The art of teaching lies not in doing things, but in getting them done, which is a very different matter. To arouse and strengthen motive, to establish and maintain the right condition for its realisation—there is our work."

Again, in *The Journal of Education* for July, 1904, one of my colleagues summarises admirably the points to be aimed at in the teaching of science in secondary schools. He says:

"You are aware of the many advantages which are claimed for science teaching—the training in manipulative skill, in exact observation, in critical comparison, in generalisation, and in logical reasoning: the cultivation of the imagination and the communication of useful information."

However much we may fall short of these high ideals, they are surely worthy of our earnest endeavour.

We shall now briefly consider,—(*a*) the conditions attached to work in day schools; (*b*) examination syllabuses; (*c*) the text-book difficulty; (*d*) a suggested scheme.

§ 2

CONDITIONS OF WORK

THE essential points which have to be taken into consideration in framing a scheme of work are these:

(1) The course is usually begun by pupils between the ages of twelve and thirteen, and continued for three or four years.

(2) The class may contain as many as thirty pupils.

(3) Probably not more than four hours per week can be devoted to the work.

(4) The average science master may or may not have some years of experience to his credit.

It is futile to disregard these factors, and to assume ideal conditions and unlimited time, as is sometimes done.

The methods adopted should be suitable to the age of the pupils, and the laboratory work should be of such a character, at least for the first two years, that each pupil or pair of pupils can conduct the same experiment at the same time.

It may be desirable, on occasion, to have two separate experiments in progress; but independent work in the case of young pupils soon leads to disorganisation of the teaching, and makes an adequate discussion of results impossible. The difficulty that the clever boy outstrips his fellows is, I believe, best overcome by setting him an additional experiment of a kind closely related to the one with which the class as a whole is engaged.

Again, the formation of good habits is of great importance; and in the early part of the first year time spent in teaching how to draw diagrammatic sections of apparatus and how to keep records will be well repaid subsequently.

In fact, in day-school work it is most desirable that the teaching of science should be correlated with the teaching of English composition and drawing.

At the outset there is much that is new, time is needed to get over initial difficulties, and a considerable period must elapse before a pupil is able to give a rational account of what may be seen and inferred when, for instance, some common substance is heated. Investigations involving much reasoning are therefore undesirable until the habits of manipulation and observation have been formed.

Further, one may be very doubtful of the value of attempting to obtain exact quantitative results before the difficulties of manipulation of the rougher qualitative kind have been overcome.

The preliminary matters indicated here will be dealt with in Vol. I., Part I., of the pupil's book.

The time at the teacher's disposal is short, and the rate of progress must be exceedingly slow if the whole course is restricted to actual experiments undertaken by the pupils.

There seems no reason, however, why the

laboratory course should not be amplified as previously suggested, provided this additional work is strictly supplementary to, and closely connected with the individual work of the pupils; in any case, constant revision and systemisation are necessary.

§ 3

EXAMINATION SYLLABUSES

For the science master who has to prepare his pupils for a public examination in a totally inadequate period I fear there is no hope, but even he may be more successful by attempting only a part of the work in the right way than by trying to scramble through the whole.

In the majority of secondary schools, however, this difficulty of time is disappearing. The boy who begins his course at twelve years of age need not enter for a preliminary examination for at least three years—ample time to get through the work prescribed by most examining bodies.

The trouble is that examination syllabuses, in many cases, give merely a bald outline of the work expected. The sin is one of "omission" rather than of "commission."

As a rule there is no guidance, no indication of the development of the course—of the sequence in which the subject *might* be taught. Not only is the science master (perhaps fresh from college or with but a year or two of experience of school life) expected to perform the routine duties attached to his office,—for instance, (1) the preparation of experiments; (2) the management of the laboratory; (3) the ordering of supplies; (4) the correction of books,—but he has also to arrange the subject-matter of a syllabus in an order suitable for teaching purposes, and to build up a course based on a series of cryptic statements, such as "Elements, compounds, the phenomena of combustion, air, water." For the man with many years' experience of teaching, who is able and willing to devote the necessary time to this work, the construction of such a course may not be a trouble; for the inexperienced science master it is a serious matter.

There is room for research here.

§ 4

The Text-book Difficulty

We may now ask what are the difficulties which confront the teacher who attempts to preserve the spirit of investigation in a school chemistry course.

A correspondent in a letter to *The School World*, February, 1905, puts the matter thus:

"In the first place, when a boy is using a book of instructions for practical work, it is very easy for him to carry out the instructions blindly without in the least understanding what he is trying to find out. I have many times gone up to a boy and asked him what he was aiming at in the experiment, to be met with the honest, if somewhat staggering reply, 'Please, sir, I don't know.'

"Secondly, when theoretical text-books are in use, there is the great danger that boys should read ahead and find out what results they are to expect in their practical work. The result is that the spirit of enquiry, in the excitement of which the value of practical work partly lies, is completely killed, while the effort of thinking out what the results of the practical work mean is evaded."

For these reasons some noted authorities on the teaching of science taboo text-books altogether; indeed, it is difficult to see how with a book printed and bound in the orthodox way the dangers which this writer has described can be avoided.

Again, it is sometimes urged that the pupil's own laboratory notebook should be his text-book, but I doubt if this view is held by many men engaged in actual school teaching: first, because the accounts of experiments, even if correct, do not form a connected course; and secondly, because any attempt to convert the laboratory notebook into a text-book would need a disproportionate amount of the time available. The absence of a book is, to say the least, an inconvenience.

Two points appear to be clear:

(1) That the book of laboratory instructions,

although it fulfils a useful function, does not fully meet school requirements. Nothing can take the place of the preliminary discussion of a problem in class, for in the early stages the printed page frequently fails to kindle interest, and the teacher cannot be sure that the purpose of an experiment is understood. The absence of sections or chapters clearing up and extending the results of laboratory work is also a disadvantage.

(2) That books in which the instructions to the pupil are immediately followed by a discussion of the results which the student should try to arrive at himself with as little aid as possible, are unsatisfactory.

On the other hand, it seems desirable that the pupils should, at a time determined by the science master, have access to printed matter giving a connected account of whatever part of the course the teacher may wish them to study as a whole.

What, then, is the method of teaching proposed ?

(1) Let us assume that the class meets in a laboratory to begin the first of a series of experiments on a definite section of the course for which a suitable sequence of experiments has been carefully designed.

It will be necessary to link up the work about to be undertaken with knowledge already possessed by the pupils, and there is no better method of doing this than by asking a few well-chosen questions. The answers received from members of the class can be enlarged upon, and these preliminary remarks should lead step by step to the statement of a problem the solution of which needs experimental work. When the teacher has convinced himself that the purport of the experiment is understood, he will, no doubt, give such verbal instructions on the method of carrying out the *first* experiment of the series as may appear to him to be required.

(2) The boys now set to work to write in their notebooks a statement of the purpose of the experiment they are about to perform, prefaced in many cases by a brief account of the steps in the argument which led to the problem.

They conduct the experiment, write down their observations, make a drawing in section of the apparatus used, and finally attempt to give an answer to the question originally proposed.

It is the first and last of these various steps in the work which are not infrequently so badly done. At the outset pupils will need much help, and possibly it may be desirable for the teacher to write out the record of one or two experiments in co-operation with the pupils. In any case a full discussion of results is necessary.

(3) In a well-designed sequence of work a discussion of the results obtained in the first experiment will lead naturally to the consideration of a second problem. It is the business of the science master to get the maximum amount of information from the class, and to lead the dis-

cussion in such a way that the need for further investigation becomes clear.

The purpose of the second experiment having been decided upon, the class may be asked for suggestions as to the means of carrying out the work practically. These proposals will probably need modification, but if suggestions are not asked for and acted upon, we cannot expect to cultivate initiative.

(4) After the second experiment has been duly recorded and discussed it may be found that apparatus is needed for the next step, of a kind which it is impossible to supply to individual members of the class, or the experiment may be one which boys should not be trusted to do alone. A demonstration is, therefore, given by the science master, and a record of the experiment is written.

(5) Finally, the series of experiments is completed, but there still remains much important work to do. A class lesson will be needed for the revision of the whole of the section which has been considered, and at this stage great care should be taken to connect together the various steps in the argument.

In some cases it may be desirable to work through a parallel series of experiments, or to amplify the work already done in some other way.

Again, some questions, either on the work done or on some closely related subject, may now be profitably considered with the class.

§ 5

A Suggested Scheme

An attempt has been made to solve some of the difficulties to which attention has been called, and the following is a brief account of my proposals :

(1) The subject-matter which must necessarily be considered in any elementary course of chemistry has been divided into a number of sections,—(*a*) Preliminary Experiments ; (*b*) Air and Combustion ; (*c*) Oxygen and Oxides ; (*d*) Acids and Alkalies, etc. Vol. I. of the pupils' text contains Sections (*a*) and (*b*), and the course has been arranged so that the scheme will be applicable to schools which devote very different amounts of time to chemistry.

(2) In order to overcome the difficulty that a text-book forestalls the practical work, the pages are not bound up in the orthodox fashion, but arrangements have been made to file the pages in a text-book cover. The printed pages or sections, as the case may be, can therefore be given out to the pupils before or after the practical work at the discretion of the science master.

(3) Each volume of the work will contain laboratory instructions (when these are deemed necessary), a general account of experiments performed by the pupils, a record of experiments which it is recommended should be shown

at the lecture table, together with such supplementary matter as appears to be necessary to make the sequence complete.

(4) The present volume is intended for the master. It contains a copy of Part II. of the pupil's text-book (Air and Combustion), and three appendices. Appendix I. includes notes on apparatus, demonstrations, and other matters. Appendix II. contains references to literature. Appendix III. gives some indication of the ground which is covered in Part I.

To carry out a scheme of this kind under the most advantageous conditions, the time available for chemistry should be allocated to laboratory work, to demonstration, and to class lessons at the discretion of the science master. On the average perhaps two-thirds of the total time would be spent in the laboratory.

There are obvious objections to the proposals made here, and no doubt there is room for considerable improvement in the pupil's book. Suggestions and corrections from teachers will be very welcome.

It is by no means an easy task to draft a sequence of suitable experiments for the laboratory, nor is it easy to correlate theory and practice, and to ensure that some real progress shall be made without disturbing that balance between "investigation" and "information" which it is so desirable to preserve.

In Part II. "investigation" rather than "information" has been emphasised, because the subject-matter appeared to offer a good opportunity of introducing the method.

While an endeavour is made to preserve the spirit of investigation in Parts I., III., etc., it is not intended to press the investigation method to extremes. Due regard must be paid to the value of information as such, and to the necessity of covering a reasonable amount of ground in the time usually allowed to chemistry in day schools.

In conclusion, it may be useful to recapitulate the advantages which the scheme would appear to possess:

(1) The difficulty that a book may forestall the laboratory work is overcome.

(2) The printed sections or chapters can be given out before or after the practical work.

(3) The book is built up as the course proceeds.

(4) Records of additional experiments suggested by the class, and of minor investigations branching off from the main line of sequence, can be filed in the right place.

NOTES ON ELEMENTARY CHEMISTRY (VOLUME I)

PART II

CHAPTER I

THE BURNING OF METALS IN AIR

§ A

In the library of the University of Leyden there is a document which was probably written as early as A.D. 200. This document is stated to be the oldest known chemical manuscript, and treats of the working of metals. The study of metals has from very early times been a subject of interest to man, and now these substances enter so largely into innumerable articles of every-day use that some of their characteristic qualities are known to all. For instance, we know that metals are capable of being polished, that some can be rolled out into sheets and drawn out into wires. Not only have the metals certain general characters which mark them off from other groups of natural objects, but each particular metal has some qualities peculiar to itself by which it can be distinguished from other metals. These qualities of a substance are called its "properties." Now, we can learn much about the properties of substances by finding out how they behave under different circumstances—*i.e.* by arranging and performing suitable experiments.

EXPERIMENT I

The Behaviour of Metals when heated

In order to ascertain how certain metals behave when heated in air, we were told (1) to heat, one at a time, small pieces of copper, zinc, and magnesium, using a Bunsen burner for the purpose; and (2) to observe carefully all that occurred.

When these metals were heated, various remarkable changes were noted, and substances were formed whose properties were quite unlike the properties of the metals with which we started.

Copper.—A piece of copper foil was heated in the Bunsen flame for a few seconds.

The flame itself was coloured bright green, whilst the copper lost its characteristic appearance and became many-coloured; red and green tints were seen.

When the metal was heated strongly, it became red-hot; and on removal from the flame the surface was seen to be dull black.

By bending or scraping the foil it was found that the black substance scaled off, exposing a surface of unaltered metal.

Zinc.—The zinc foil bent in the flame and shrivelled up.

When heated more strongly, the metal appeared to catch fire, bluish green flashes of light were seen, and part of the surface became covered with a dull yellow substance, which turned white on cooling and was easily powdered.

Magnesium.—This metal, in the form of thin ribbon, readily caught fire and burned with a dazzling white flame. As the flame crept along the ribbon a cloud of white smoke ascended in the air, and a white mass was left hanging downwards from the burning metal. Some of the white stuff dropped on the bench and broke into small pieces. The whole of the white mass was brittle and easily powdered.

CHAPTER I (*continued*)

THE BURNING OF METALS IN AIR

§ B

THE question now arose—Why were the metals altered in this way? It was pointed out that both the copper and the zinc became red-hot, but only the surface of these metals was changed. Therefore the changes were not due to heat alone. Some members of the class thought that the changes observed were due to the flame; others were of opinion that the air was in some way concerned.

EXPERIMENT II

The Action of Heat on Magnesium: (*a*) in the Presence of Air; (*b*) in the Absence of Air

In order to find out whether either of these explanations was correct, the following experiments were carried out:

(*a*) Some members of the class heated magnesium in a crucible so that the flame was excluded, but air had access. In this case a white residue was obtained, as in the first experiment.

(*b*) Others heated a piece of magnesium in a crucible, the magnesium being covered with sand to exclude as much air as possible. It was found that the magnesium appeared unchanged.

Similar experiments were made with zinc and copper, and in neither case did any change occur in the absence of air.

It was therefore concluded that:

(*a*) Direct contact with the flame is unnecessary.

(*b*) Air has something to do with the changes which these metals undergo when heated in air.

It was further thought that this explanation would account for the surface character of the changes noted in the cases of copper and zinc (Exp. I.).

We were now able to say that:

(1) The metals magnesium, copper, and zinc are changed in appearance and in properties by heating them in air.

(2) The air in some way brings about these changes; for if care be taken to heat the metals apart from air, no change in appearance occurs.

The next step was to try to find out what part the air takes in these changes.

CHAPTER I *(continued)*

THE BURNING OF METALS IN AIR

§ C

WE were told that although some of the changes which metals undergo when heated have been known from very early times, yet men did not succeed in finding out the truth about burning until they began to measure the quantities of materials used in their experiments.

EXPERIMENT III

Does any Change in Weight occur when Magnesium is converted into Magnesium Ash?

It was therefore decided to try the following experiment, with the object of finding out whether the "white ash" obtained as the product of burning magnesium weighed the same as the magnesium before burning.

A piece of magnesium contained in a covered crucible was placed on the left-hand pan of a balance, and sand was added to the watch-glass resting on the right pan until the crucible was counterpoised. The latter was heated strongly, and air was admitted occasionally by slightly raising the lid (Fig. 1).

Care was taken to prevent the escape of the ash in the form of smoke. When cold, the crucible containing the ash was replaced on the left pan of the balance. It was now found that the white ash weighed more than the magnesium. Something must therefore have been added to the magnesium, and, since we had found out by Exp. II. that the air was concerned, it seemed likely that air had been added to the magnesium. This was at least a possible explanation of the increase in weight observed.

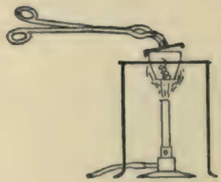

Fig. 1.

If this is the *true* explanation of the increase in weight, a quantity of air must be used up when magnesium is burnt in it.

CHAPTER I *(continued)*

THE BURNING OF METALS IN AIR

§ D

After some consideration it was suggested that if the magnesium could be burnt in a closed space containing a known quantity of air, it might be possible to observe whether any air disappeared. If air disappeared this would confirm us in the opinion that air was added to the magnesium in the last experiment.

EXPERIMENT IV

The Burning of Magnesium in a Fixed Volume of Air

Finally it was agreed to burn a piece of magnesium in a crucible floating on water, the whole being covered with a bell-jar of air (Fig. 2).

(1) The crucible was floated.

(2) The bell-jar, without the cork, was placed over it, and the level of the water, the same inside as outside, was marked with a piece of gummed paper.

(3) The bell-jar was removed and the

magnesium lighted; the bell-jar was immediately replaced and the cork inserted.

(*a*) The magnesium was seen to burn.

(*b*) The water within the jar was first depressed owing to the expansion of the enclosed air.

(*c*) The water gradually rose in the jar to a fixed point (Fig. 2, *b*).

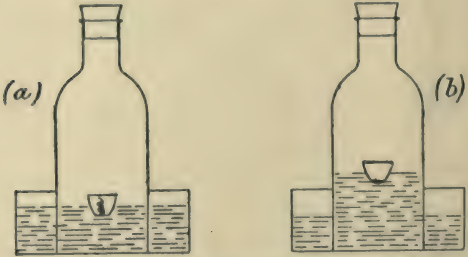

Fig. 2.—The burning of magnesium in a closed space.

In order to see whether the air left in the jar was ordinary air a lighted taper was placed in the gas; the light went out. It is therefore obvious that the gas left behind in this experiment is not ordinary air.

We were now able to say that:

(1) Magnesium increases in weight on burning.

(2) A fixed volume of air diminishes in volume when magnesium is burnt in it.

Both these results can be explained if we suppose that magnesium on burning combines with air.

CHAPTER I (*continued*)

THE BURNING OF METALS IN AIR

§ E

EXPERIMENT V

Does the Whole or Part of a Given Volume of Air combine with Metals?

Another problem now suggested itself. When metals burn in air, will all the air combine with the metal if sufficient metal be present, or does only part of the air take part in the burning, as seems to be probable from the results obtained in Exp. IV.?

It was suggested that after adjusting the level of the water in the trough the attempt might be made to burn a second piece of magnesium in the gas remaining in the bell-jar, with the object of noting whether any further decrease in volume occurred.

We were told, however, that magnesium does not behave towards air in exactly the same way as other metals, and that in order to obtain a result which would be true in the case of metals generally, copper would be used.

A further difficulty had now to be overcome, for copper does not burn readily like magnesium, and thus an experiment could not be carried out in a bell-jar. It was therefore necessary to arrange an experiment in a different way. Finally it was determined to pass a known volume of air over copper contained in a tube and heated from the outside. Arrangements were also made to collect that portion of the air (if any) which did not combine with the copper.

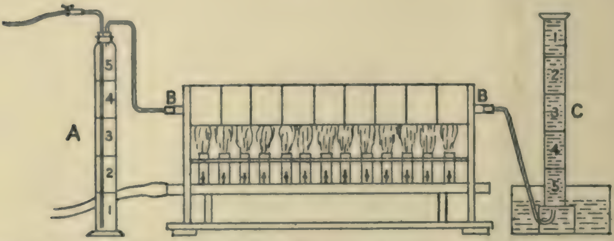

Fig. 3.—The passage of a fixed volume of air over heated copper.

Two experiments were shown us:

(1) Copper was observed to gain in weight on heating, as the magnesium had done.

(2) A known volume of air contained in the cylinder A was made to pass over heated copper in BB by allowing water to run very slowly into A (Fig. 3). A portion of the air collected in the cylinder C. It was found that about four-fifths of the air passed over into C, and this, like the residue left behind in the magnesium experiment, would not allow a taper to burn in it. A

quantity of copper more than sufficient to combine with all the air in C was used, and hence we know that only a portion of any given volume of air will combine with heated copper.

Question.—How could the apparatus be modified so as to pass the air backwards and forwards over the copper several times?

CHAPTER I (*continued*)

THE BURNING OF METALS IN AIR

§ F

Discussion

The question now arose—how can we explain the fact that only part of the air combines with certain metals?

If we imagine that the air contains two different gases, one of which is capable of combining with metals whilst the other is unable to do so, the results obtained in the previous experiments become intelligible.

It was suggested that if we could get back the gas which combined with the magnesium or the copper, its properties might be compared with those of the gas left behind after burning these metals in air; if these were found to be different, then air must consist of at least two distinct substances.

It was pointed out, however, that a very hot flame was used to burn the copper, and the ash from the magnesium was also formed at a very high temperature. It therefore appeared unlikely that these ashes when merely heated again would release the gas with which the metals combined.

It was argued that if we are to release the combined gas, we must experiment with an ash that has been formed at a lower temperature; such an ash might possibly be found to split up again when strongly heated.

Only a few metallic ashes are formed at low temperatures—for example, mercury ash, lead ash (red lead).

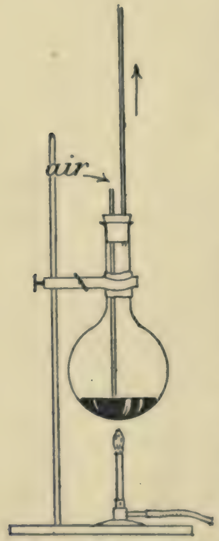

Fig. 4.—The formation of a small quantity of mercury calx.

EXPERIMENT VI

The Preparation of Mercury Calx [1]

A small quantity of mercury ash or calx may be prepared in the following way (Fig. 4):

Mercury contained in a flask provided with inlet and outlet tubes is heated just to boiling by means of a small Bunsen flame.

In the course of a few hours black specks appear on the surface of the mercury. On continuing the heating for two days and allowing to cool a red powder is formed.

The mercury is poured off and the powder collected.

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[1] See Appendix I., p. 98.

EXPERIMENT VII

The Decomposition of Mercury Calx

We heated some of the red powder in a test-tube and found that (1) the calx became very dark and gradually diminished in bulk; (2) the mercury reappeared in small drops, which formed a mirror on the side of the tube; (3) and at the same time a gas was given off, which allowed a taper to burn very brightly in it, and even rekindled a glowing splint of wood.

From this experiment it was concluded that the part of the air which combines with mercury is quite different from the gas which does not combine with it (see Exp. VIII.).

Air is therefore not a simple substance, but consists of at least two gases:

(1) The gas which combines with mercury and allows a taper to burn in it, to which the name "oxygen" has been given.

(2) The gas which remains behind after burning metals in a confined volume of air, and which does not allow a taper to burn in it. This gas has received the name "azote."

EXPERIMENT VIII

Lavoisier's Experiments[1]

In 1774 Dr. William Priestley, an eminent dissenting minister, discovered that oxygen could be obtained from mercury calx. In the same year Priestley visited Paris, where he met the famous French chemist Lavoisier, whom he told of his experiment. Shortly after Priestley's visit, Lavoisier devised and carried out the important experiments described below.

---

[1] See Roscoe and Schorlemmer, Vol. I.; and *The Study of Chemical Composition*, by Ida Freund.

1. **Production of the Mercury Calx**.—Into a glass retort having a long, straight neck, Lavoisier placed four ounces of pure mercury; he then bent the neck so that, when the retort rested on the top of a charcoal furnace, the end of the bent neck appeared above the surface of the mercury contained in the trough T, thus placing the air in the bell-jar in communication with that in the retort (Fig. 5).

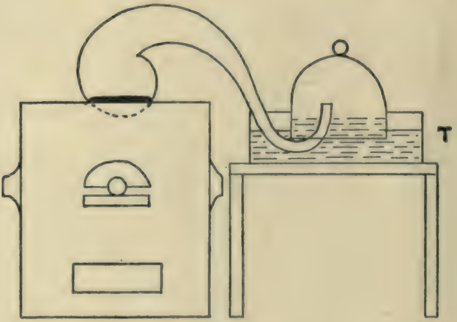

Fig. 5.

The volume of air contained in the bell-jar and retort was carefully measured.

The mercury in the retort was now heated to near its boiling point. Beginning from the second day, red specks were formed on the surface of the mercury, and these increased in quantity for some days.

By the twelfth day no further formation could be noticed.

The fire was put out, the volume of air left in the bell-jar was measured, and the red substance was collected and weighed.

The results were :

Volume of air at the beginning ... ... = 50 cubic inches.
Volume of air at the end = 42 to 43 cubic inches.
∴ Volume of air absorbed by the mercury ... = 7 to 8 cubic inches.
Weight of red substance = 45 grains.

Lavoisier found that the air left behind was no longer fit to breathe. Small animals introduced into it died in a few minutes, and lights were immediately extinguished.

2. **Decomposition of the Mercury Calx.**—The 45 grains of red substance were placed in a very small retort, arranged so that it could be heated (Fig. 6).

On heating, metallic mercury was deposited in the colder parts of the tube and a gas was given off.

The volume of gas was measured and the mercury weighed.

The results were :

Weight of red substance taken = 45 grains.
Weight of mercury found ... = $41\frac{1}{2}$ grains.
∴ Weight gained by mercury ... = $3\frac{1}{2}$ grains.
Volume of gas evolved ... = 7 to 8 cubic inches

This gas was found to allow a taper or charcoal to burn vigorously in it, and it could be breathed by animals.

At a later date Lavoisier showed by direct experiment that the 7 to 8 cubic inches of gas weighed 3½ to 4 grains.

3. On repeating experiments (1) and (2) Lavoisier found that on adding the 7 to 8 cubic inches of gas to the 42 to 43 cubic inches of gas left in the bell-jar, he obtained an air in all respects like atmospheric air.

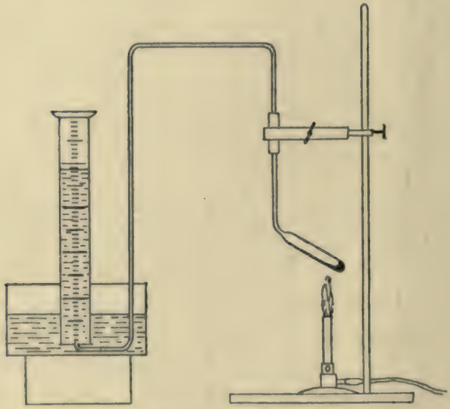

Fig. 6.—The decomposition of mercury calx.

Note that Lavoisier,—

(1) Regained a volume of gas in experiment (2) equal to that which disappeared in experiment (1).

(2) Proved that the weight gained by the mercury was equal to the loss of weight suffered by the air.

(3) Showed that the two gases had different properties.

(4) Reformed the original volume of air by mixing together the two gases obtained from air.

He thus came to the conclusion that atmospheric air is composed of two distinct gases.

CHAPTER I (*continued*)

THE BURNING OF METALS IN AIR

§ G

Summary and Extension

CERTAIN conclusions have now been arrived at as to the composition of air, and incidentally we have gained some knowledge of the gases oxygen and azote and of metals.

Air. – Lavoisier showed that the atmosphere which surrounds our world is composed of at least two gases.

About one-fifth of any fixed volume of air consists of oxygen, whilst the remaining four-fifths is occupied by a gas to which Lavoisier gave the name " azote " (*a-zoe* = without life). At a later date it was found that azote appeared to be identical with a gas present in nitre or saltpetre. The name " azote " was dropped, and the gas present in air and in nitre was called " nitrogen." Quite recently, however, it has been shown that azote is not pure nitrogen; it is a mixture containing a very large proportion of nitrogen and a very small proportion of other gases, of which an inert gas called "argon" is the most abundant.

100 c.c. of Lavoisier's azote contain about—
99 c.c. nitrogen,
1 c.c. argon, etc.

We shall therefore continue to call the mixture left behind after the burning of metals in air "azote."

Oxygen is a colourless gas contained in air.

The gas combines directly with the metals magnesium, zinc, copper, mercury, and, in fact, with all the well-known metals except platinum, gold, and silver.

A taper burns more brightly in oxygen than in air, and a glowing splint of wood is rekindled by the gas; but the gas itself does not burn.

Since oxygen combines so readily with many other chemical substances it is said to be a chemically "active" substance.

Nitrogen is also a colourless gas contained in air, of which it forms about four-fifths by volume.

Unlike oxygen, it does not allow a taper to burn in it (neither does it, as a rule, combine directly with metals).

Nitrogen is an inert or chemically "inactive" substance, and is characterised more by the things it does not do than by the things it does.

Metals.—Of the metals examined one was a liquid—namely, mercury; this is the only metal known to be liquid at the temperature of the atmosphere.

All the other metals known, of which there are about sixty, are solids.

Metals generally possess a peculiar bright appearance, usually described as a "metallic lustre," because this character is a common property of metals. Some other substances, however, such as galena, iodine, iron pyrites, have a "lustre" resembling that of metals.

We know from experience that the common metals are heavier bulk for bulk than many other substances, and sink when dropped into water. The metal aluminium, however, is a comparatively light substance, and there are some metals which are sufficiently light to float on water. To describe all metals as heavy, bright, solid substances, is therefore incorrect. Again, they are good conductors of heat and electricity; for instance, a poker placed in the fire becomes hot throughout its length; electric light leads are always made of metal, and usually of copper.

Some metals when heated in the presence of air undergo remarkable changes in appearance. These changes are accompanied by a gain in weight, heat is given out, and in some cases the chemical action is so vigorous that the temperature rises to the kindling point, and the metal will go on burning when the source of heat is removed—light is the result.

The gain in weight is due to the chemical combination of the metal with a gas present in air—oxygen.

Oxides.—When metals are heated in air, they are, as a rule, converted into new substances which possess essentially different properties.

These new substances are called "oxides."

The progress of adding oxygen to a substance is called "oxidation." We say, for instance, that copper is "oxidised" by burning it in air.

This union of a metal with oxygen may be expressed by an equation[1] thus:

$$\text{Magnesium} \underset{\text{(chemically combines with)}}{+} \text{oxygen} \underset{\text{(and produces)}}{=} \text{magnesium oxide}$$

Many oxides are white, others are coloured; for example,—

Magnesium oxide is white,
Copper[2] oxide is black,
Mercury[2] oxide is red,
Zinc oxide is white when cold, but yellow when hot.

In the case of many oxides (copper, magnesium, zinc), the oxygen cannot be driven off by heating to a high temperature.

On the other hand, mercuric oxide (and a few other oxides) are decomposed on heating strongly.

---

[1] Note the meaning of the signs + and = here.

[2] Other oxides may be formed under certain conditions; for example, red copper oxide, yellow or black mercury oxide.

Steps in the Argument

(1) Certain metals are changed in appearance on heating in air, and the products have properties unlike the metals (Exp. I.).

(2) The air takes part in these changes (Exp. II.).

(3) The metal magnesium increases in weight on burning (Exp. III.).

(4) When the burning takes place in a closed space some air disappears. It therefore appears probable that the increase in weight of magnesium is due to the addition of air (Exp. IV.). The air left is not ordinary air.

(5) One-fifth of a fixed volume of air combines with copper when air is passed slowly over the heated metal. The remaining four-fifths of the air behaves like the gas left behind in (4) (Exp. V.).

(6) All these experiments become intelligible if we assume that air contains two gases in different proportions—one of which combines with metals and one which does not do so.

(7) It does not seem possible by heating the calx to regain the air which combines with magnesium and copper.

(8) But on strongly heating some calx of mercury a gas is given off which rekindles a glowing splint of wood. This gas is different in kind from that left behind in previous experiments. Therefore air contains at least two gases.

Explanation of some Terms used in Chemistry

Mercuric oxide on heating breaks up into two substances—mercury and oxygen.

This process is called "chemical decomposition," or simply "decomposition." There is a very large number of substances which can be decomposed by heat or by some other chemical means into two or more distinct substances. This class of substances is called "compounds," or "decomposable substances."

On the other hand, there is a limited number of substances which have resisted all attempts to decompose them. These are called "undecomposable substances," or "elements."

For example, no chemist has succeeded in obtaining a second substance from mercury alone. Every particle of mercury appears to consist of mercury and nothing else.

At some future time it may be found that some of these elements are decomposable.

Definitions

Chemical combination is the union of two or more substances (elements or compounds) to form a single substance whose properties are essentially different from those of either of its constituents.

Chemical decomposition is the splitting up of a compound into two or more essentially different substances (elements or simple compounds).

An *element* is a substance which chemists have been unable to split up into simpler substances.

A *compound* is a substance every particle of which is composed of two or more elements united together to form a substance essentially different from either of its constituents.

Questions

(1) A small quantity of a certain substance is placed in a crucible and weighed. The crucible is then heated strongly, and after cooling is again weighed. A loss in weight is observed. What deduction may be made from this experiment?

(2) A litre of air is passed slowly through a long tube containing copper turnings heated to redness. What volume of azote might be collected? How would you measure its volume? Make a careful drawing of the apparatus you would use.

(3) In Question (2) it is stated that a long tube is used. Is this necessary, and, if so, why?

(4) What would be the result of passing a fixed volume of (1) oxygen, (2) azote, over hot copper in the manner described in Question (2)? Would the rate at which the gas is passed over make any difference to the result?

(5) For what useful purposes are iron, copper, lead, and silver used? Mention one property peculiar to each of these metals. How would you distinguish lead from silver?

(6) What is azote? How would you obtain it from air? If you were asked—How is

nitrogen prepared? what answer would you give?

(7) Given two cylinders, one containing oxygen and the other nitrogen, how would you find out which cylinder contained oxygen?

(8) Mention some of the properties common to many metals.

(9) Oxygen gas is a chemically active substance. Explain what this means.

(10) Calculate the number of grains of mercury and of oxygen in 100 grains of mercury oxide from the figures obtained by Lavoisier in his analysis of mercuric oxide.

(11) Express in the form of equations the union of oxygen with mercury, zinc, lead.

(12) Give examples of oxides which (1) can, (2) cannot, be decomposed by heat.

(13) In what respect does oxygen (1) resemble, (2) differ from, azote?

(14) Describe briefly how oxygen gas was obtained from air by Lavoisier.

(15) A piece of metal is burnt in air; another piece of the same metal is burnt in oxygen. A gain in weight is observed in each case, and the products are found to have the same properties. What deductions do you make from these experiments?

CHAPTER II

THE BURNING OF PHOSPHORUS IN AIR

§ H

After the examination of the burning of some metals in air, it was decided to investigate the burning of some non-metallic substance, and to test whether it behaved towards air in the same way as the metals. Since it was very desirable to experiment with a substance which would burn readily, phosphorus—a substance used in the manufacture of match-heads—was chosen.

EXPERIMENT I

The Burning of Phosphorus in Air

Phosphorus was burnt in a small crucible, covered with a cylinder containing air as shown in Fig. 7. This substance burnt very brightly, and the cylinder was filled with a dense white cloud.

After the burning was over the contents of the cylinder were examined and found to consist of a white powder. The general effect was like the burning of

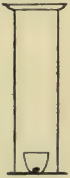
Fig. 7.

magnesium, in that the phosphorus was converted into an essentially different substance. In a very short time, however, the powder disappeared, and oily drops were seen on the inside of the cylinder. The powder is therefore of a different nature from the oxides obtained by burning metals in air.

EXPERIMENT II

Does any Change in Weight occur when Phosphorus burns in Air?

To continue the comparison with metals, an experiment was arranged to find out if the white powder weighed more or less than the phosphorus. This may be done as described below (Fig. 8).

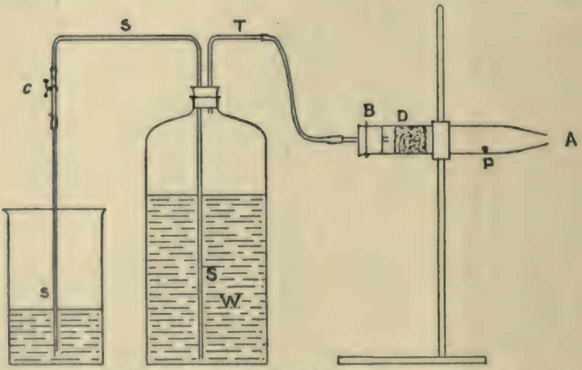

Fig. 8.—The burning of phosphorus in a current of air.
s s s = Syphon.
P = Small piece of phosphorus.
c = Clip.
D = Asbestos wool.
A B = Glass tube.

To conduct the experiment SS is filled with water by blowing down the tube T, and the clip C is then closed.

AB with its contents is weighed, and then attached to T.

On releasing the clip C, water syphons out of W and air enters at A.

The phosphorus is kindled by momentarily warming the tube AB, and if the current of air is carefully regulated the phosphorus fumes are caught by the asbestos D. On again weighing AB a gain in weight is observed.

CHAPTER II (*continued*)

THE BURNING OF PHOSPHORUS IN AIR

§ I

EXPERIMENT III

The Burning of Phosphorus in a Closed Space containing Air

It was argued that if the gain in weight in the case of phosphorus was due to its combination with oxygen, as in the case of the metals, a decrease in volume equal to about one-fifth of a fixed volume of air should occur when phosphorus is burnt in a closed space. To decide this point phosphorus was burnt in a bell-jar over water, and an attempt was made to measure the volume of air used up.

The bell-jar, open at both ends, was placed in position (Fig. 9, *a*), and the level of the water, the same inside as outside the jar, was marked with a small label.

The glass rod RD was greased with vaseline to make it slide readily through the cork.

A small porcelain basin containing a piece of phosphorus was floated on the water in the trough, and covered with the bell-jar.

After heating the end D of the rod in a Bunsen flame the cork bearing the rod was inserted, and the latter adjusted until it just came in contact with the phosphorus. The rod was immediately raised into position (*b*).

(*a*) The phosphorus caught fire, and the jar was soon filled with a dense white smoke.

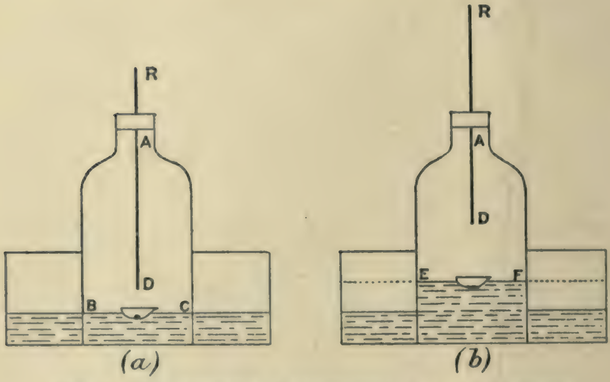

Fig. 9.—The burning of phosphorus in a closed space containing air.

(*b*) The level of the water within the jar was at first depressed; soon, however, the water began to rise, and the smoke appeared less dense.

(*c*) After a time the interior became quite clear again, and the water ceased to rise.

The volumes ABC and AEF were measured by inverting the bell-jar and filling it to the paper-marks with water from a graduated cylinder.

As in the case of metals, about one-fifth of the original volume of air disappeared. It was inferred that phosphorus combines with oxygen and not with nitrogen, and the white powder is an oxide of phosphorus (phosphoric oxide).

The oxide gradually disappeared, and it was thought probable that this substance dissolved in water.

Evidence of the correctness of this view was obtained by shaking up a fresh quantity of the oxide with water in a gas jar, when the white oxide immediately disappeared.

The results obtained by the class did not agree very well, and it was shown that if the level of the liquid BC or EF was not marked exactly, or if the water poured into the jar was a little above or a little below the mark, a considerable error would be made owing to the width of the jar. It was therefore decided to try and obtain a better result by using a narrow vessel.

CHAPTER II (*continued*)

THE BURNING OF PHOSPHORUS IN AIR

§ J

EXPERIMENT IV

The Composition of Air by Volume

It is unnecessary to heat phosphorus in order to make it combine with oxygen. Phosphorus placed in air smoulders and gradually uses up the oxygen.

This property can be used in order to determine the volume composition of air more exactly, in accordance with the following instructions (see Fig. 10):

(1) Have ready,—

(*a*) A piece of copper wire about one and a half times as long as the tube AA provided (Fig. 10);

(*b*) A large gas cylinder half full of cold water.

(2) Measure the volume of air contained in the long nar-

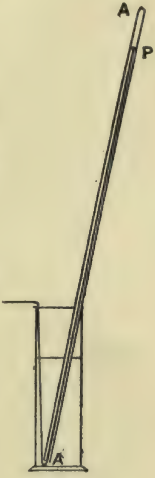

Fig. 10.

row tube AA by displacing it with water. Note down the volume.

Again fill the tube AA with water and support it in a vertical position on the bench or on the floor with the aid of a retort stand.

(3) Boil some water in a beaker, then turn out the Bunsen burner.

(4) Half fill a test-tube (of lesser diameter than the tube AA) with cold water, and drop into it one or two small pieces of phosphorus. Now immerse the test-tube in the hot water until the phosphorus just melts and forms a layer at the bottom of the tube. Then put one end of the wire into the molten phosphorus, and run cold water from the tap on the outside of the test-tube until the phosphorus solidifies.

(5) Carefully transfer the phosphorus to AA and push it through the water nearly to the end of the tube by means of the wire.

(6) Now invert the tube AA over a sink so that all the water may run out, and the tube fill with air.

When the last drop of water has run out, immerse the open end of AA under the water contained in the cylinder.

(7) Attach a label, upon which you have written your name, to the cylinder.

(8) Allow to remain until next lesson.

(9) Note that the water has run into the tube to a certain height.

We have now to measure the volume of the azote left.

Be very careful not to touch the tube AA above the level of the water inside it; if you do the azote will expand and an incorrect result will be obtained. Proceed as follows:

(10) Fill the cylinder to the brim with water. Withdraw the wire with the phosphorus attached to it—this is somewhat difficult, and must be done slowly, a little at a time.[1] *At once put the phosphorus under the water. Be very careful not to allow any air to enter the tube.*

(11) Now arrange the tube AA so that the level of the water inside it is the same as that of the water in the cylinder.

Mark the level of the water in AA with a strip of gummed paper.

(12) Measure the volume of the azote. State your results thus:

Volume of air in A ... ... c.c.
Volume of azote ... ... c.c.
Volume of oxygen ... ... c.c.

Calculate the number of c.c. of azote and of oxygen in 100 c.c. of air.

---

[1] Demonstration.

CHAPTER II (*continued*)

THE BURNING OF PHOSPHORUS IN AIR

§ K

These experiments make it clear that the burning of phosphorus in air resembles in all important respects the burning of a metal, such as magnesium.

(1) The products of combustion weigh more than the substance burnt. This is due to a chemical combination of the burning substance with oxygen.

(2) The proportion by volume of the air used up is the same.

EXPERIMENT V

No Change in Total Weight occurs when Phosphorus is burnt in a Closed Space containing Air

One other experiment was shown us which proved that there is neither a gain nor a loss in weight when phosphorus burns in a confined volume of air. This was done in the following way:

A small piece of phosphorus was dropped into a dry, round-bottomed flask, which was then securely corked.

The flask and its contents (phosphorus and air) were weighed.

On gently warming the flask the phosphorus caught fire and the vessel was filled with a white cloud of phosphoric oxide.

On again weighing, the vessel was found to weigh the same as before.

Since, however, phosphorus gains in weight on burning, and air loses weight (Exps. II., III.), it is evident that the weight gained by phosphorus during burning is exactly equal to the weight lost by air.

Questions

(1) Describe the appearance of phosphorus. How is it stored in the laboratory? and what precautions should be taken in handling this substance?

(2) Compare the properties of magnesium oxide and phosphoric oxide.

(3) Describe all that can be seen when phosphorus burns in a crucible covered by a cylinder of air.

(4) If the air in Question (3) were replaced by oxygen, what difference would this make?

(5) Refer to Fig. 8, and explain why air enters at A when the clip is released.

(6) A small piece of phosphorus was placed in a long dry test-tube. The test-tube was heated in a Bunsen flame at a point about 2 inches from the open end, and drawn out so that the phos-

phorus was closed in a tube shaped like a pointed pencil. Sketch the tube. The phosphorus was gently warmed, and after cooling, the fine point of the tube was broken under water. Explain what you would expect to happen.

(7) Explain exactly how a piece of phosphorus may be attached to the end of a wire. What did you see when phosphorus was exposed to air at the ordinary temperature ?

(8) Make a series of lettered sketches to show the various steps in carrying out Exp. IV.

(9) Try to devise a piece of apparatus to show that when magnesium burns in a confined volume of air there is neither a gain nor a loss in total weight.

(10) Give the name of an oxide (*a*) soluble in water, (*b*) insoluble in water.

CHAPTER III

THE BURNING OF A CANDLE IN AIR

§ L

It is interesting to inquire whether the burning of a candle is, or is not, a phenomenon of essentially the same kind as the burning of metals or of phosphorus.

Facts previously established are that (1) air is composed of oxygen and azote; (2) a candle (a taper) does not burn in azote.

If when a candle burns the essential feature of the action is a *combination* of the candle substance with a constituent of air, the union must be with oxygen.

Proposition 1.—Let it be assumed that combination with oxygen does occur.

Now it is a matter of daily experience that a burning candle gradually diminishes in size, but no visible product of combustion comparable with magnesium oxide or phosphoric oxide is formed.

Proposition 2.—It is reasonable to infer that the product or products of combustion are invisible, and therefore probably gaseous.

In order to test whether these "propositions" are true or false, experiments must be conducted similarly to those already made in the case of magnesium and phosphorus. If the experimental results cannot be explained in the way suggested, then either one of the propositions is wrong or both are wrong, and some other possible explanation must be sought and the truth of our suggestions again tested by experiment.

If the experimental results can be explained by our suggestions, further evidence of their correctness must still be sought.

EXPERIMENT I

The Burning of a Candle under Given Conditions

If Proposition 1 is correct we should expect—

(1) A lighted candle covered with a glass cylinder to go out when the oxygen had been used up.

(2) A candle to burn for a longer time in a large cylinder than in a smaller one.

Directions

Try these experiments. Record your observations and conclusions.

CHAPTER III (*continued*)

THE BURNING OF A CANDLE IN AIR

§ M

RESULT OF EXPERIMENT I

A LIGHTED candle was covered with a glass cylinder containing air. The flame became smaller and smaller, and in a very short time went out.

The experiment was repeated with a larger cylinder, but in this case the flame was not extinguished so soon.

The assumption that oxygen is used up in the burning renders these results intelligible.

In both experiments a "mist" was seen to collect on the inside of the cylinders. The production of the mist was discussed in class, and it was concluded that one of the products of the burning is a vapour which condenses in minute drops of liquid on the cooler portions of the glass, and thus becomes visible.

EXPERIMENT II

Attempt to collect the Liquid Product of Combustion

It was now decided to obtain, if possible, a quantity of this liquid for examination.

It was argued that it would be necessary—(1) to burn a candle for a considerable time, (2) to arrange for a constant supply of air, (3) to condense the vapour by cooling it.

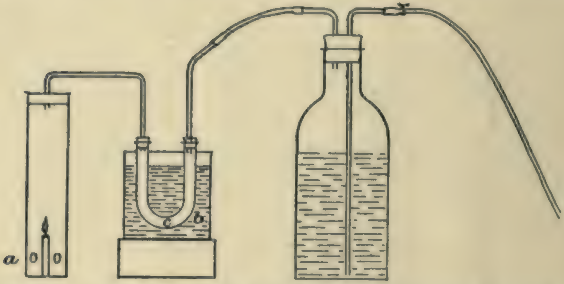

Fig. 11.—Aspiration of the products of combustion through a cold tube.

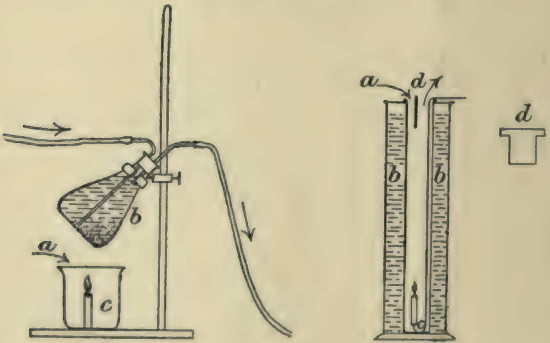

Fig. 12. Fig. 13.

Condensation of the liquid product.

Places at which (*a*) air enters, (*b*) vapour condenses, (*c*) liquid collects, (*d*) partition shown in section and in elevation.

The experimental methods of doing this, indicated in Figs. 11, 12, 13, were discussed.

After a time a colourless liquid was obtained which looked like water.

A determination of the density of the liquid, and of its boiling point, indicated that the liquid was water. White copper sulphate was shown to turn blue with water and with the liquid.

Conclusions

Water is one product of the combustion of a candle.

If oxygen does combine with the candle substance (Proposition 1), and water is the only product of combustion, then water must contain oxygen.

CHAPTER III (*continued*)

THE BURNING OF A CANDLE IN AIR

§ N

EXPERIMENT III

The Burning of a Candle in a Closed Space containing Air

When bodies burn in air the decrease in volume of the air may be roughly measured by carrying out the experiment in a bell-jar over water (see § § D and I).

If oxygen is used up in the burning of a candle (Proposition 1) we should expect the volume of air within a bell-jar to diminish by one-fifth, for the water vapour formed during the burning will readily condense. If, however, more than one product is formed during the burning (as is possible, since candle-wax may contain several elements which combine with oxygen) it is invisible and probably gaseous.

In these circumstances the volume of gas left within the jar when cold will depend on the solubility of the gas in water.

Definite information on these points may be sought by the aid of an experiment carried out in accordance with the following:

Directions

(1) Support the candle in a small bottle (Fig. 14).
(2) Arrange the closed glass tube or glass rod (*ap*) so that the end (*p*) can be made to touch the free end of the wick.
(3) Mark the level of the water with gummed paper.
(4) Remove the bell-jar and take out the cork.
(5) Light the candle to soften the wick, then put out the light and cap the wick with the head of a wax vesta match.
(6) Cover the candle with the open bell-jar.
(7) Warm the end (*p*) of the rod in a Bunsen, insert the cork bearing the rod, move the bell-jar until (*p*) just touches the match-head.

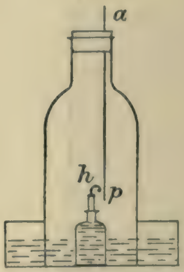

Fig. 14.—The burning of a candle in a closed space.

Observe all that happens. Cool the bell-jar by repeatedly filling a small beaker with water from the trough and pouring the contents over the jar.

Mark the level of the water within the jar ten minutes after the candle goes out, *but do not yet remove the jar.*

Number and record all your observations, and finally state,—

(1) Original volume of air in the bell-jar.
(2) Volume of gas left after ten minutes.
(3) Volume of gas left at end of lesson (or at next meeting of class).
(*a*) Try to suggest an explanation for each of your observations.
(*b*) Do you think that any substance other than water was formed during the burning?
(*c*) What substance placed in the bell-jar after the completion of the experiment would enable you to prove the presence or absence of oxygen? How would you introduce this substance without removing the bell-jar from the water?

CHAPTER III (*continued*)

THE BURNING OF A CANDLE IN AIR

§ O

EXPERIMENT III

Observations

(*a*) An increase in volume was noted during the burning.

(*b*) The water afterwards, however, rose slowly in the bell-jar.

(*c*) Volume of air within the bell-jar = 2 litres. Decrease in volume after ten minutes = $\frac{1}{17}$th of original volume.

(*d*) A further decrease in volume was noted after allowing the apparatus to stand for some time, but the total decrease was less than $\frac{1}{5}$th of the original volume of air.

Discussion

The increase in volume observed (*a*) was due, in part, at least, to the expansion of the air caused by the high temperature of the candle-flame; a gas may have been formed, but no definite conclusion can be drawn from this observation.

The rise of the water in the bell-jar (*b*), and the continued decrease in volume for some hours (*d*), indicate that some product was formed which dissolved slowly in water.

If water vapour had been the only product, then no contraction in volume would have occurred *after the apparatus had cooled.*

These results become intelligible if we assume that an invisible gas—soluble in water—was formed during the burning.

Since we know that a candle does not burn in azote, the decrease in volume indicates that oxygen was used up during the burning (Proposition 1).

We still have to explain why the total decrease was not equal to one-fifth of the original volume of air (*d*). Possibly a point was reached when the air became so poor in oxygen that the candle would no longer burn, and thus some oxygen remained.

This was found to be the true explanation, for when a piece of phosphorus fixed on the end of a wire was introduced through the water into the gas remaining in the bell-jar, the phosphorus smouldered, and after a time a further small decrease in volume occurred.

Conclusions

(1) When a candle burns in air oxygen takes part in the burning.
(2) Two products of combustion are formed:
(*a*) Water vapour;
(*b*) A gas which dissolves slowly in water.

CHAPTER III (*continued*)

THE BURNING OF A CANDLE IN AIR

§ P

Further Evidence of the Truth of Propositions 1 and 2

1. (*a*) *Oxygen is concerned in the burning.*—Had no oxygen been used up in the burning, then a large decrease in volume equal to one-fifth of the original volume of air would have taken place when phosphorus was introduced into the bell-jar (Exp. III.).

Only a small contraction in volume was observed.

(*b*) *Oxygen combines with constituents of the candle substance.*

(i) If oxygen does combine with the candle substance, then the products of combustion formed in a given time should weigh more than that part of the candle which disappears in the same time.

It has been found that the substance soda lime (a mixture of caustic soda and lime, *u*) will catch and absorb both the water and the gas formed during the burning (Fig. 15).

A method of conducting this experiment is described below:

(1) First the whole apparatus is suspended on a balance and weighed.
(2) The candle is lighted and the cork replaced.
(3) The whole apparatus is again suspended on the balance.

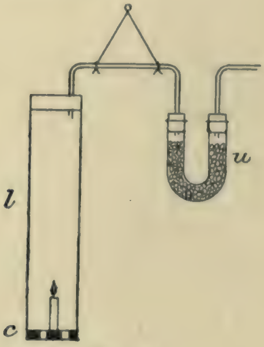

Fig. 15.

(4) A gain in weight is soon observed.

Hence the water vapour and the gas absorbed by the soda lime together weigh more than that part of the candle which has disappeared.

(ii) This conclusion may be confirmed by burning a candle in a bell-jar of oxygen over water.

The candle burns more brightly than in air.

A contraction in volume occurs.

The same products are formed as when the candle burns in air.

But identical products must contain the same elements.

Hence when a candle burns in air oxygen combines with the constituents of candle-wax.

2. *An invisible gas is formed during the burning.*—If a candle is burnt in a cylinder of air, and then certain substances are added, various changes are observed.

For example,—

(i) Blue litmus paper is coloured purple ;
(ii) Clear lime water becomes white.

These changes occur even when the water vapour formed is previously removed [see 1 (*b*), i].

The changes must be due to the action of an invisible gas.

CHAPTER III *(continued)*

THE BURNING OF A CANDLE IN AIR

§ Q

EXPERIMENT IV

Attempt to decompose the Gaseous Product

THE main points established by our experiments are these:

(1) Air loses oxygen when a candle is burnt in it.

(2) A candle burns in oxygen, and a decrease in volume occurs.

(3) The products of combustion [in (1) and (2)] are the same.

(4) The products of combustion formed in a given time weigh more than that part of the candle which disappears in the same time.

These results indicate that either the gas, the water vapour, or in all probability both these substances, contain oxygen combined with some element or elements present in candle-wax.

If some substance (such as heated magnesium) which combines readily with oxygen is introduced into the gaseous product of combustion it is possible that the oxygen may be removed, whilst the unknown element or elements may be set free—in other words, the decomposition expressed in the following equation may occur:

$$\underset{\text{Oxygen}+\substack{\text{unknown}\\ \text{element(s)}}}{\text{Gas}} + \text{magnesium} = \text{magnesium oxide} + \text{unknown element(s).}$$

The following directions indicate a way of performing such an experiment:

Directions.—(1) Have ready a piece of magnesium attached to a deflagrating spoon.

(2) Obtain some of the gas by burning a candle in air contained in a clean cylinder.

(3) Kindle the magnesium, and introduce it into the gas.

(4) Examine the cylinder thoroughly. Then add a little water, filter, and examine the residue carefully.

Does the magnesium burn in the gas?

What substances appear to be formed, and how do you account for their presence?

EXPERIMENT V

Attempt to decompose the Liquid Product—Water

We have seen that water is formed when a candle burns in air.

Previous experiments have led us to suppose that the water formed is produced by the combination of oxygen in air, with some substance (say B) derived from candle-wax.

Now magnesium begins to combine with oxygen only when heated to a certain temperature; if, then, we attempt to decompose water with the aid of magnesium, thus,—

$$\underset{\text{Oxygen + B.}}{\text{Water}} + \text{magnesium} = \text{magnesium} + \text{B},$$

the experiment should be tried at a high temperature. This can be done as follows:

Directions.—(1) Boil some water in a wide-necked litre flask until steam is escaping freely.

(2) Then suspend a burning piece of magnesium wire in the steam.

(3) Record your observations.

Do you think the steam was decomposed?

Did you see any trace of the substance B?

If a substance (B) is liberated from the steam, of what nature do your observations lead you to expect it to be—a solid, a liquid, or a gas?

Try to devise a piece of apparatus to test the truth of your ideas. Sketch.

CHAPTER III (*continued*)

THE BURNING OF A CANDLE IN AIR

§ R

EXPERIMENT IV (*continued*)

The Decomposition of the Gaseous Product

Discussion

The magnesium, when introduced into the gas, continued to burn for some time, and magnesium oxide appeared to be formed.

On carefully examining the interior of the cylinder and the residue left on the filter, a few small particles of a black substance were seen. We were told that this black substance is called "carbon." It therefore appeared probable that the gas contains at least two substances in combination—oxygen and carbon.

We were reminded, however, that this deduction was based on incomplete evidence,—first, because the white powder had not been proved to be magnesium oxide; secondly, because the black substance had not been investigated by us at all.

We were told, however, that the gas did

contain oxygen and carbon, and that the name "carbon dioxide" has been given to it.

In confirmation of this statement two experiments were shown to us:

(1) Candle-wax shavings were shown to become black when treated with hot sulphuric acid—indicating the possibility of the presence of carbon in wax.

(2) Carbon when burnt in oxygen produced a gas which, on testing with lime water and litmus, caused exactly the same changes as the gas produced by a burning candle. Hence the same gas—carbon dioxide—was formed in each case.

Summary.—(1) During the burning of a candle carbon of the wax combines with oxygen of the air, forming a soluble gas—carbon dioxide.

(2) When magnesium is burnt in carbon dioxide the gas is decomposed, oxygen combines with the magnesium, forming magnesium oxide, and carbon is set free.

CHAPTER III (*continued*)

THE BURNING OF A CANDLE IN AIR

§ S

EXPERIMENT V (*continued*)

The Decomposition of the Liquid Product—Water

Discussion

Magnesium continued to burn in the steam, and magnesium oxide appeared to be formed.

It was inferred that the steam had been decomposed, and that magnesium had combined with the liberated oxygen.

No trace of the substance or substances with which oxygen is combined in water was seen.

It was therefore thought that the substance(s) B must be invisible and possibly gaseous.

The following method (Fig. 16) of burning magnesium in steam was discussed and tried.

The water in the flask was boiled until steam escaped freely.

The magnesium wire was lighted, and the cork (*c*) quickly inserted. A gas collected in L.

First the tube T and then the burner were removed.

The gas when tested with a lighted taper was found to burn.

This gas, we were told, was called hydrogen, because it was found to be a constituent of water.

Summary.—(1) When a candle burns the

hydrogen contained in wax combines with the oxygen of the air, forming water vapour.

Water is not therefore an element; it is an oxide.

(2) When magnesium is burnt in steam the water is decomposed. Oxygen unites with the magnesium, forming magnesium oxide, and hydrogen gas is set free.

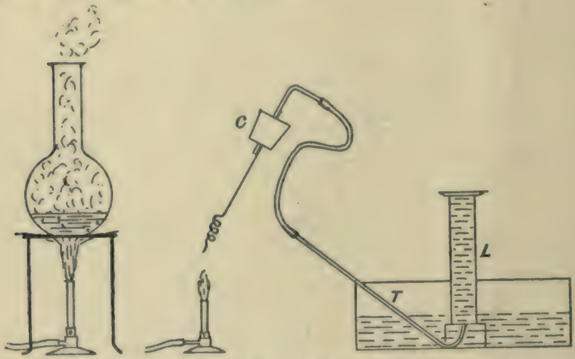

Fig. 16.—The burning of magnesium in steam.[1]

This decomposition can be expressed as follows:

Water + magnesium = magnesium oxide + hydrogen.
Oxygen + hydrogen.

There are still many points about a burning candle which we have not considered at all; for instance:

(1) Of what use is the wick in a candle?

(2) What is the wick made of?

(3) What becomes of the wick when burnt?

Add to this list any questions which may occur to you.

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[1] See D. S. Macnair, *An Introduction to Chemistry*.

CHAPTER III

THE BURNING OF A CANDLE IN AIR

§ T

Summary and Extension

In Chapter I. the general behaviour of certain metals when heated in air was studied. This led up to a consideration of Lavoisier's classical experiments, by which he proved that mercury under suitable conditions combines with a portion of the air. In Chapter II. it was seen that the phenomenon of burning phosphorus could be explained in the same way.

This collection of experience led us to suspect that a combination with oxygen occurs when other substances are burnt in air.

The burning of a candle was then studied, and this suspicion was verified by experiments.

It is therefore important to realise that a comparison of the results of different experiments, and the recognition of the points of similarity in them, make it possible to predict what is likely to occur in some unknown case of the same kind.

If now the three series of experiments dealt with in Chapters I., II., and III. are compared, it will be found possible to classify the results in two ways.

(1) *Points of Agreement*

(*a*) Each substance on burning underwent a profound change.
(*b*) There was an evolution of heat during the burning.
(*c*) The products of combustion weighed more than the original substances.
(*d*) Combination with oxygen took place.

(2) *Points of Difference*

(*a*) The temperature at which combination commenced was different for different substances. Phosphorus began to unite with oxygen at the temperature of the air; copper required to be strongly heated.
(*b*) In some cases combination with oxygen resulted in the production of flame; in other cases no flame was seen.
(*c*) Whilst in the case of the metals the products of combustion were solids, a gas and a liquid were formed during the burning of a candle.

The essential feature common to these experiments, and to a large number of other cases which have been investigated by scientific men, is the union of the burning substance with a portion of the air called "oxygen."

The oxygen unites with burning substances forming with them new substances, which together weigh more than the combustible substances did before being weighed.

The increase in weight is equal to the weight of the oxygen which has at the same time disappeared from the air.

The steps, then, which lead up to such a general conclusion are these:

(1) The experimental study of a few cases in detail.

(2) The comparison and classification of the results of experiments which have something in common.

The deduction is then made that "what has been observed in a limited number of cases" is probably true of "a multitude of yet unexamined cases."[1]

Note, however, we do not *know* until we have *experimented.*

Carbon Dioxide.—Carbon is an element which forms an important constituent of all substances which are commonly used for lighting and heating purposes—wood, oil, coal, etc. When these substances are burnt the carbon combines with the oxygen in air, forming carbon dioxide gas, which is discharged into the atmosphere.

The presence of this gas in air may be detected by exposing a little lime water in a watch-glass for an hour or two.

[1] See Ostwald, *The Principles of Inorganic Chemistry.*

The atmosphere receives carbon dioxide from other sources.

Rooms crowded with people soon become "stuffy," and the quality of the air depreciates so much that it becomes unhealthy to breathe.

This is in a large measure due to the fact that the air breathed out differs from the air breathed in by containing a much larger proportion of carbon dioxide. Just as phosphorus slowly combines with oxygen at the ordinary temperature, so the oxygen taken into the lungs finds its way into the blood, and is carried by blood-vessels to all parts of the body, with the result that waste material containing carbon is burnt up.

The carbon dioxide formed in this way is liberated and breathed out on return of the blood from the body to the lungs.

Again, in the processes of decay and putrefaction carbon dioxide is formed.

It would therefore appear that the quantity of oxygen in the atmosphere must be diminishing, and the quantity of carbon dioxide increasing. This, however, is not the case, for the composition of air is practically constant, and further, the amount of carbon dioxide in a given volume of pure air is small.

The air of towns contains about 4 volumes per 10,000.
Country air ,, ,, 3 ,, ,, ,,

The explanation is that the green leaves of plants have the power to decompose carbon dioxide; the oxygen is restored to the air, whilst the carbon is built up into compounds which form an essential part of plant food. Plants perform this useful function only in sunlight.

Water Vapour.—The existence of water vapour in air is not surprising when we remember that three-quarters of the globe's surface is covered with water—oceans, seas, lakes, rivers.

The amount varies from day to day, and is dependent on the temperature; for example:

A cubic yard of air at 30° F. will hold about $\frac{1}{6}$ oz. of water vapour.

A cubic yard of air at 50° F. will hold about $\frac{2}{6}$ oz. of water vapour.

A cubic yard of air at 70° F. will hold about $\frac{4}{6}$ oz. of water vapour.

The presence of water in air may be shown in many ways.

(1) If a glass vessel containing ice is brought into a room moisture is seen to collect on the outside of the glass. The air surrounding the vessel is cooled down to a temperature at which it is no longer able to hold so much water in the state of vapour—the excess is deposited on the glass as dew.

(2) Again, if air be aspirated through a U tube which is kept cool a considerable quantity of water may be collected.

(3) Sulphuric acid (oil of vitriol) absorbs water vapour. A beaker containing a little of the acid increases in weight when exposed freely to the air.

(4) Calcium chloride—a dry white granular compound—is frequently used for the purpose of drying gases. This substance if exposed to air becomes damp and increases in weight.

The Composition of Air

We have seen that air contains two important constituents — oxygen and azote — as well as small and varying quantities of carbon dioxide and water.

You have been told that azote is a mixture containing a very large proportion of nitrogen, and small quantities of other gases, the most abundant of which is argon.

More exact analyses than we have been able to make show that air deprived of its water and carbon dioxide contains—

$$\begin{array}{l}
21{\cdot}0\,\%\ \text{oxygen,}\\
\left.\begin{array}{@{}l@{}}78{\cdot}2\,\%\ \text{nitrogen}\\ \underline{\quad{\cdot}8}\,\%\ \text{argon}\end{array}\right\}\text{azote.}\\
\underline{\underline{100{\cdot}0}}
\end{array}$$

Ordinary country air contains about ·03 % carbon dioxide, and an average of 1·47 % of water vapour.

The impure air of towns differs from pure air in the following points:

There is a larger percentage of carbon dioxide and of acid substances due to the burning of various materials used in manufactories.

There are floating impurities—dust, soot, and living organisms.

Law of Indestructibility of Matter

In the experiments we have studied we have found that changes in the amount of the substances taking part in a chemical action constantly occur. A gain in weight is found on burning metals in air, whilst mercuric oxide on heating loses weight.

On the other hand, it has been seen that when phosphorus burns in a closed space so that no matter can either enter or leave the vessel, no change in *total weight* is observed, although the phosphorus disappears and another substance is produced.

Again, it has been seen that the substance of a candle is not really destroyed on burning, but is merely converted into other bodies. If the candle or any other combustible substance is burned in a closed space containing air, or in such a way that all the products are taken into account, no change in total weight is observed.

These simple experiments do not prove that matter cannot be destroyed, but they do illustrate a principle which has been found to be true of all the chemical actions which have been investigated, namely:

The total weight of the substances taking part in any chemical change remains unchanged.

Questions

(1) What reason have you to suppose that the gas produced in burning a candle is also present in air?

(2) In what respects does town air differ from country air?

(3) Why does a candle burn more brightly in oxygen than in air?

(4) Devise a piece of apparatus to show that coal gas will not burn without a supply of air.

(5) Explain the terms "combustion," "combustible." Oxygen is sometimes said to be a "supporter of combustion." What does this mean? Mention a "non-supporter of combustion."

(6) Mention substances capable of absorbing (i) carbon dioxide, (ii) water vapour.

(7) What arrangement of apparatus would you devise to collect a large bottleful of air free from carbon dioxide and water?

(8) A small volume of liquid alcohol contained in a basin was lighted. After the burning the basin was found to contain no liquid. How do you account for this result?

(9) What experiment might you perform to test the correctness of your explanation?

(10) A small jet of coal gas is to be burnt within a closed bell-jar so that the effect on the volume of air may be noted. Sketch, letter the apparatus, and briefly describe what you would expect to happen.

(11) Describe the appearance of the following substances — sulphuric acid, phosphoric oxide, calcium chloride, anhydrous copper sulphate. Write brief notes about each, mentioning any purpose known to you for which these substances are used. What does "anhydrous" mean?

(12) Tabulate the following substances as elements or compounds — copper, zinc oxide, phosphorus, water, carbon dioxide, lead, platinum, phosphoric oxide, magnesium.

(13) What elements and compounds are present in air?

(14) Give examples of chemical decomposition.

(15) From what sources does air derive carbon dioxide?

(16) How is the accumulation of carbon dioxide in air prevented?

(17) How can the amount of oxygen in air be determined?

(18) How would you attempt to obtain a visible quantity of water from air.

(19) Mention some metals which (1) are, (2) are not, converted into oxides on heating in air.

Additional Experiments

(1) Examine the effect of heat on iron wire and platinum wire. Compare the results obtained.

(2) Arrange an apparatus so that air may be passed through a hard glass tube containing a roll of copper gauze. Weigh the tube and the

gauze. Heat strongly; re-weigh. Record results.

(3) Find the loss in weight which mercuric oxide undergoes when heated strongly.

- (i) Weigh a hard glass test-tube filled with a plug of glass wool.
- (ii) Place in the tube 1-2 grms. of the oxide, and replace the plug; weigh.
    - Heat strongly; weigh.
    - Re-heat a second time; re-weigh.
    - Calculate the loss in weight which 100 grms. of the oxide would suffer.
    - Why is there any loss in weight at all?

(4) Devise an arrangement so that a candle can be burnt in a closed flask with the object of showing that no alteration in total weight occurs. Submit your sketch for approval.

(5) (*a*) Find the action of heat on litharge; (*b*) devise an apparatus for heating litharge in a current of air so that any change in weight may be observed. Now heat the product to a temperature higher than it has previously been subjected. Write a full account of your work and discuss the relation of the product to litharge.

(6) Put a few sprigs of watercress in a gas jar, fill the jar with tap-water, and place the vessel in sunlight. Watch from time to time without moving the jar. Record your observations, and carry out any simple experiment which may occur to you, with the object of learning something more about the things you have observed.

APPENDIX I

NOTES ON THE COURSE COVERED IN PART II

GENERAL

The study of combustion may be approached in several different ways.

It is possible to start with the consideration of the action of heat on metals, the burning of phosphorus, the burning of a candle, or of some other substance.

The order adopted is that which the author, in the course of many years' teaching experience, has found to work well.

Drawing should form an important part of the course. Neat pencil sketches of apparatus should be insisted upon. These should, as a rule, show the apparatus in section. This method is the most suitable for diagrams, and, moreover, the average boy of twelve to fourteen cannot make a model drawing quickly and accurately.

Careful teaching is required.

The printed sections A—T are intended to supplement and amplify the records made by pupils. It is strongly recommended that no sections (laboratory directions excepted) should be given out until the pupil's records are as complete as they can be at the particular stage of their development. Keep back the printed matter too long rather than give it out too early.

If care is taken in the initial lessons, the improvement in the pupils' ability to express themselves clearly at the end of three months' work should be marked.

EXPERIMENTS

The Burning of Metals

(1)* Heat directly in the flame.

(2) Point out that it will be necessary to continually ask the question "why."

Elicit suggestions as to the cause of the changes seen in (1).

Point out the necessity of testing these "guesses" by experiment.

Try to obtain suggestions as to how the experiment may be carried out.

(3) Obtain suggestions as to method from the students. It is much better to counterpoise here than to weigh, because the problem requires a very simple answer.

The introduction of the idea of number will only confuse the issue.

(4) It will probably be difficult to elicit the idea of using a closed space—a flask may be suggested. Remove cork or bung—immerse bell-jar in the trough and mark level of water with gummed paper. Light magnesium, immediately cover with the bell-jar, and insert the bung quickly.

The question of the volume of air used up is not required at this stage.

(5) (*a*) Use copper filings. A Ramsay burner will do.
(*b*) See Newth's *Lecture Experiments.*
See note (6)

(6) This experiment may be started at the end of the lesson dealing with (5). Use a round-bottomed flask. 50 c.c. of mercury. One tube should end just above the surface of the mercury. Adjust the flame so that the mercury shall be heated just to its boiling point. In an actual experiment described by Dr. D. S. Macnair (*An Introduction to Chemistry*, Geo. Bell & Sons), 1·36 grm. of the oxide was formed in twenty-eight hours.

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* These numbers refer to the experiments.

The Burning of Phosphorus in Air

The experiments in this series, with the exception of (2), are suitable for students.

The students should now be able to suggest the order of work.

(1) Warn as to dangerous nature of phosphorus.

Young boys should not be allowed to cut pieces from a stick of phosphorus.

Small pieces ready for use should be kept in a bottle of water.

Have Bunsen burners turned down when phosphorus is being used.

A warm wire is a convenient object for igniting phosphorus.

(2) Demonstration only suggested.

The experiment requires care. Use a small piece of phosphorus and carefully regulate the rate of aspiration.

(3) It is usually desirable for boys to repeat this experiment.

(4) This experiment is so important that it should be done by all.

The method described in Newth's *Lecture Experiments* is too dangerous for boys, but the teacher might with advantage supplement the work of the class by a demonstration.

All Bunsen burners should be turned out before the phosphorus is transferred to the tube A.

(5) The flask, preferably a round-bottomed one, must be quite dry.

If a small pad of asbestos is placed inside the flask upon which the phosphorus can rest the risk of breakage is lessened.

The cork should be secured with string or wire.

The Burning of a Candle

All that it is necessary to show at this stage is that the phenomenon of a burning candle is similar to that of the other cases of combustion previously considered.

After much consideration, however, it was thought that the inclusion of the section dealing with the decomposition of carbon dioxide and water would make for progress.

Some of the experiments described in this chapter may be demonstrated by the teacher, but there is no reason why most of the experiments should not be carried out by the pupils if time can be spared for the further study of combustion. The method of treatment is slightly different from that adopted in the previous chapters, but in all cases the directions for experiment and the discussion of the results have been separated, so that the various sections can be distributed at times fixed by the teacher.

It is not intended that even the "directions, etc.," should be given out until after the preliminary discussion of the problem before the class.

(2) This experiment will probably be demonstrated.

The apparatus should be set up on the day before the lesson. If, however, the experiment is attempted by the class, the anhydrous copper sulphate test for water might be done by all, and the density and boiling point experiments demonstrated.

(3) A bell-jar marked to show (*a*) the original volume of air, (*b*) the diminution in volume after ten minutes, and (*c*) the volume after twelve hours (say), will be useful to the teacher when the time arrives for the discussion of results. It is therefore advised that the experiment should be tried some days before the class lesson.

The whole of the section "Further Evidence of the Truth of Propositions 1 and 2" might form the subject of one or more class lessons.

APPENDIX II

LITERATURE

Title	Author	Publisher	Published Price
Some reference books:			
A Treatise on Chemistry. Vol. I.	H. E. Roscoe and C. Schorlemmer	Macmillan	21/- net.
Alembic Club Reprints:			
(1) Experiments upon Magnesia Alba, etc.	Jos. Black	Cambridge Univ. Press	1/6 net.
(2) Foundations of the Atomic Theory	Dalton, Wollaston, and Thos. Thomson	,,	,,
(3) Experiments on Air	Henry Cavendish	,,	,,
(4) Foundations of the Molecular Theory	Dalton, Gay Lussac and Avogadro	,,	,,
(5) Extracts from Micrographia	R. Hooke	,,	,,
(6) On the Decomposition of the Alkalies and Alkaline Earths	Humphry Davy	,,	,,
(7) The Discovery of Oxygen, Part I.	Joseph Priestley	,,	,,
(8) The Discovery of Oxygen, Part II.	Carl Wilhelm Scheele	,,	,,
Annual Reports on the Progress of Chemistry	Issued by the Chemical Society	Gurney & Jackson	4/6
Chemical Lecture Experiments	G. S. Newth	Longmans	6/-

TITLE	AUTHOR	PUBLISHER	PUBLISHED PRICE
Essays on Historical Chemistry	T. E. Thorpe	Macmillan	12/- net.
History of Chemistry	E. Von Meyer	,,	15/- net.
Introduction to Physical Chemistry	J. Walker	,,	10/- net.
The Methods of Glass Blowing	W. A. Shenstone	Longmans	2/6
The Principles of Chemistry. 2 vols.	D. Mendeléeff	,,	36/-
The Principles of Inorganic Chemistry	W. Ostwald	Macmillan	18/- net.
The Study of Chemical Composition	Ida Freund	Camb. Univ. Press	18/- net.
Some suggestive text-books, etc.:			
Chemical Arithmetic	S. Lupton	Macmillan	4/6
Chemical Theory for Beginners	L. Dobbin and J. Walker	,,	2/6
Experimental Chemistry:			
Part I. Introductory	J. E. Reynolds	Longmans	1/6
,, II. Non-Metals	,,	,,	2/6
,, III. Metals	,,	,,	3/6
,, IV. Carbon Compounds	,,	,,	4/-
Inorganic Chemistry	W. A. Shenstone	Arnold	4/6
Introduction to Chemistry	D. S. Macnair	Bell	2/-
Introduction to the Study of Chemistry	W. H. Perkin and B. Lean	Macmillan	2/6
Textbook of Inorganic Chemistry	I. Remsen	,,	16/-
			DATE
Some recent papers:			
Address to Young Science Teachers	By one of H.M. Inspectors of Schools	Journal of Education	July '04
Chemistry in American Secondary Schools	T. M. Lowry	School World	Dec. '06

Title	Author	Publisher	Date
Discipline in the Laboratory	(Correspondence)	School World	Sept. Nov. '04
Glass Working for School Laboratories	A. H. Fish	,,	July, '04
Humanism and Realism as Forces in Higher Education	F. W. Westaway	Journal of Education	May, July '05
Laboratory Notebooks	C. E. Browne	School World	Jan. '06
Method of Teaching the Atomic Theory	T. P. Nunn	,,	March '06
Science Teaching and the Theory of Science	T. P. Nunn	Educational Times	May '05
Some Recent Educational Reformers (Prof. H. E. Armstrong)	F. H. Hayward	Journal of Education	May '05
The Need of Co-operation between Humanists and Realists	(Correspondence)	School World	Jan-June '04
The Laboratory Assistant	G. F. Daniell	,,	March '06
The Preparation of Crystals	A. E. Dunstan	,,	Oct. '04
The Rusting of Iron	G. T. Moody	Trans. Chem. Soc.	April '06
The Text-book in the Teaching of Science	(1) (Unsigned article)	School World	Nov. '04
	(2) G. C. Donnington	,,	Feb. '05
			Published Price
Three notable books:			
Education	H. Spencer	Williams & Norgate	2/6
The Teaching of Scientific Method	H. E. Armstrong	Macmillan	6/-
Talks to Teachers on Psychology, and to Students on Some of Life's Ideals	W. James	Longmans	4/6

APPENDIX III

Scope of Part I.

(1) The Bunsen burner.
(2) (*a*) The balance.
    (*b*) Simple manipulative exercises.
(3) The measurement of volume—graduated vessels.
(4) Exercises involving observation and description. Examination of crystals, non-crystalline bodies, mixtures, viscous and mobile liquids.
(5) Exercises involving experiment, observation, and description. The effect of heat on common substances, amplified by a demonstration of the expansion of solids, liquids, and gases. The thermometer. Melting point.
(6) Exercises involving a gain or loss in weight.
(7) The action of water on substances—solution, crystallisation, evaporation, distillation, boiling point.

Printed by Hazell, Watson & Viney, Ld., London and Aylesbury.

J.M. 13/12/46

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